Chapter 7: Surviving the Debris Environment

I. Current Activities and Research

The need for protection from orbital debris is influencing the design of new spacecraft. In the past, spacecraft design took into account the natural meteoroid environment. New NASA and DOD spacecraft designs now consider the additional hazards from human-made orbital debris.

Missions can also be planned from the outset to avoid debris-threatening situations. For example, congested altitudes could be avoided, consistent with mission objectives. The NASA Shuttle program has implemented flight rules to fly the Orbiter whenever possible in an orientation having the least hazard from potential orbital debris and meteoroid impacts (that is, with tail forward and payload bay facing the Earth).

Proper treatment of disposable components should also be part of mission planning. For example, NOAA, DOD, NASA and other agencies have begun requiring that some of the hardware involved in upper stage separation be kept attached to the upper stage rather than float away as separate debris objects.

II. Opportunities for Improvement and Future Research

A. Mission Design and Operations

Spacecraft and launch systems can be designed and operated in ways that reduce their vulnerability to the debris environment. The acceptability of any given vulnerability reduction strategy is a function of the mission objective of the space system. Mission design and operations is an option for using current systems in alternative ways to reduce impact hazards. Orbit selection is feasible for some spacecraft missions but not practical for others without significant mission objective compromise. For example, the same observations made from different orbits might require different instruments of varying cost and complexity.

B. System Protection

Spacecraft can be protected from serious damage by using shielding and by designing the spacecraft to be damage tolerant (i.e., providing redundant systems for critical functions with proper separation to prevent single event catastrophes). The most straightforward approach to meeting the protection requirement is shielding. Although shielding against meteoroids has always been a consideration, the existing and anticipated levels of threat from orbital debris make shielding more important. In addition, much of the man-made debris falls into larger size categories than the naturally occurring debris. The method of shielding to be used can significantly affect the design of the spacecraft in configuration, performance, and cost and must be part of the design philosophy from the outset. NASA and DoD have pursued several distinctly different approaches to shielding research. These approaches have proven valuable and should be continued.

Hypervelocity Impact Testing and Facilities. Proposed research includes the capability to determine the effects of projectile shape, density, and velocity on a variety of spacecraft systems using light-gas gun facilities launching projectiles to 8 km/sec and to develop ultra-high speed launchers to 15 km/sec. NASA has developed an inhibited shaped charge launcher that propels gram-size projectiles to 12 km/sec. The Department of Energy (DOE) has developed a technique to launch disks to 10 km/sec. These test methods are required to qualify spacecraft protection systems and to validate hypervelocity impact analysis models such as hydrocodes. Close coordination between NASA, DOE, and DOD should be continued.

Modeling Impact Effects. Research is recommended to develop advanced methods for accurately and efficiently predicting the response of spacecraft structures to impact, including internal shock wave propagation, material phase change, deformation, perforation, and long-term structural effects. Particular attention could be directed to modeling impact response of nonhomogeneous materials, such as composites, ceramics, fabrics, and layered materials, using advanced modeling methods and nonclassical hydrodynamic approaches. Predictive models for impact damage and catastrophic failure of pressurized tanks and other stored energy devices are needed. Modeling effects on complete spacecraft, in addition to discrete sections, need development.

Stored Energy Component Failure Modes. Experimental and analytical programs are needed to understand and predict the hypervelocity impact response of spacecraft systems containing stored energy.

As observational data improves, the largest uncertainty in predicting the future environment is the uncertainty of these breakup models.

Shielding Concepts. This research area could develop shielding concepts for both fixed and deployable shields. The effort could emphasize lightweight designs using advanced materials such as fiber composites or layered materials that pulverize instead of fragment, creating less hazardous debris and capturing a majority of the collision products. EVA-friendly techniques to deploy on-orbit augmentation shield concepts could also be a subject of the effort. A major goal might be to develop effective shielding concepts for debris up to 2 cm in size (approximately 10 to 15 grams) with speeds up to 15 km / sec.

Design Guide, Validation and Certification. This research area uses techniques from all four previous areas and develops analytical and test methods for qualifying the survivability of the entire spacecraft. A design handbook and / or guide could be developed and updated as new knowledge becomes available to assist designers of all future spacecraft in designing optimized protection systems for their spacecraft. Extension of shield capability to such a regime would eliminate one half of the residual risk between current shield capability and SSN collision warning capability.

Closely related to survivability is the concept of redundancy. With redundant systems physically separated on the spacecraft, a collision with debris that damages one or more systems or instruments might still allow the spacecraft to continue functioning.

The ultimate objective of hypervelocity impact research is to develop methods to optimally configure a spacecraft to minimize the damage from meteoroid / debris impact. This involves the assessment of spacecraft response to penetrating impact and the prediction of internal damage. NASA has developed an analysis code called BUMPER to determine the probability of impact damage to spacecraft using currently accepted meteoroid and debris environment models. A program called ESABASE has been developed by ESA for similar purposes. These programs require periodic updating with new knowledge gained from hypervelocity impact tests and modeling that predict the impact response and failure conditions for various spacecraft structures. These programs and additional methods could then be used to compare different techniques for spacecraft shielding, mission design and operations, and redundancy options on the basis of expected safety benefits, weight requirements, spacecraft reliability, performance levels, and costs. The result of the comparisons can be used to select the optimum protection system configuration that includes the best combination of shielding, mission design, operations, and redundancy.

C. Collision Avoidance

Collision avoidance is feasible if one has precise knowledge of the orbits of the objects of interest. It is feasible to construct a ground radar system with the requisite capability, but it is costly.

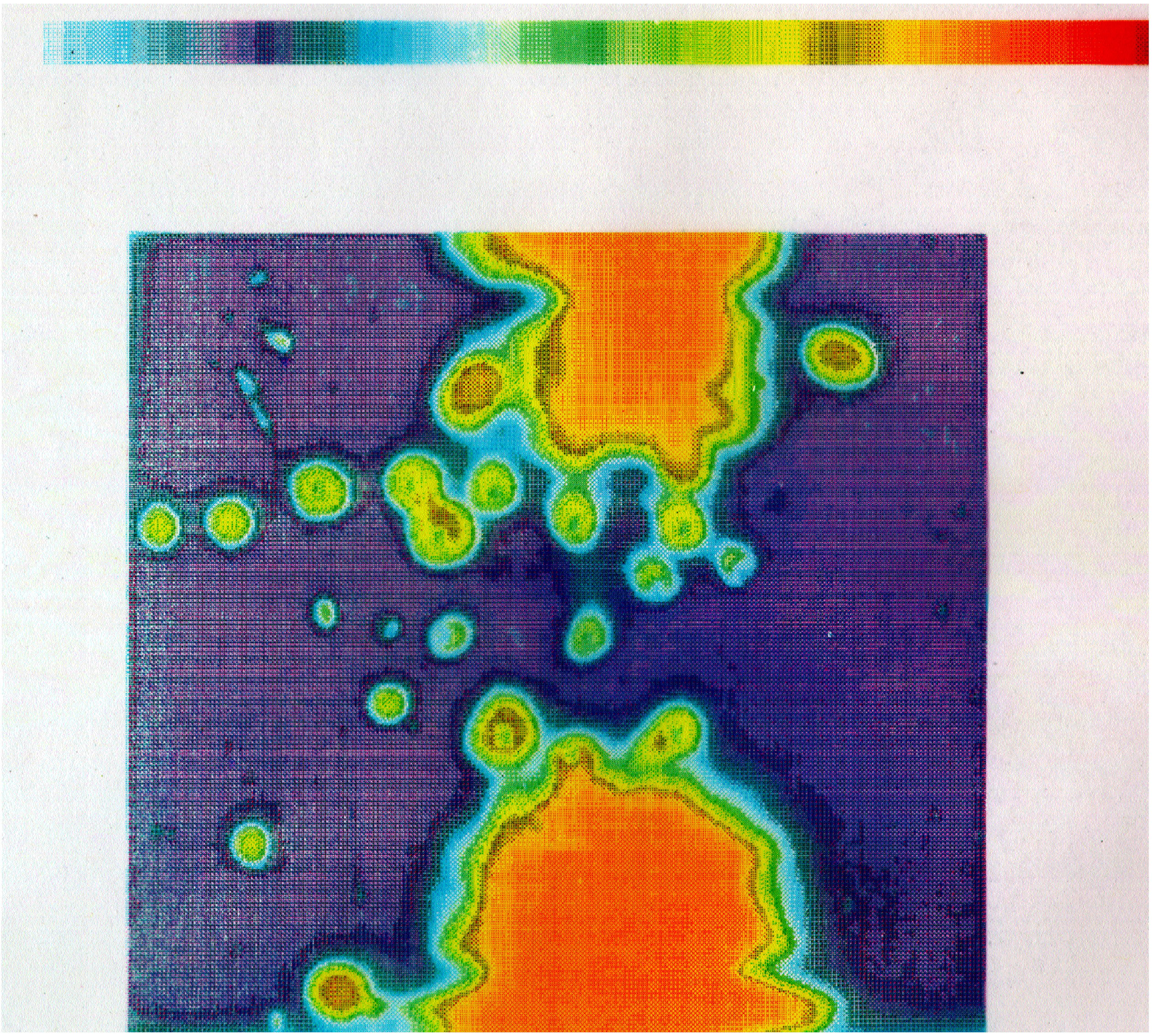
Currently, the warning can only be provided by the existing SSN. There are several limitations to the existing SSN for collision avoidance. The locations of the sensors are not well suited to a collision-warning function because they were sited to meet different criteria. A second important SSN issue is sensitivity. As stated earlier in this report, the minimum size object that can be reliably detected in LEO is about 10 cm in diameter; yet avoidance of particles of 1 cm diameter or larger is desirable. This could require an increase in sensitivity of a factor of 100, requiring a major redesign of most sensors. The increased sensitivity would result in a large increase in the number of objects maintained in the catalog, resulting in a corresponding increase in required computational resources needed.

The current SSN is used to provide collision warning during Shuttle operations. When the Shuttle is on orbit, the SSN monitors its flight path and when another object is forecast to enter a volume 25 km ahead or behind and 10 km above, below or to the side, tasking is initiated to improve the orbit data. In addition, if the object is then forecast to enter a volume 5 km along track of 2 km above, below, or to the side, a maneuver is initiated if it does not compromise mission objectives. Since this practice has been in effect, the warning envelope has been entered 26 times and the maneuver envelope 4 times, and maneuvers have been performed on 3 occasions.

NASA has established the concept of a collision avoidance network that could provide collision warning for most intersections of debris greater than 1 cm with all spacecraft of interest. To achieve the required performance, the system must operate at X-band, and the stations must be so located that every object will pass through the field of view of one of the sensors within two revolutions. To accommodate the large inventory of objects that would be cataloged and to manage the tasking of the sensors, would require a parallel processor system. To create the new catalog requires an X-band “fence” to initiate the detection and cataloging of those objects below the threshold of the current catalog.

Such a system could have an ephemeris uncertainty of 400 m along track for currently cataloged objects contrasted to the 5 km of which the SSN is capable. Recent evidence suggests that providing the required ephemeris accuracy for smaller objects will pose a challenging technical problem.

The ground system could be complemented with an onboard optical sensor that could resolve ambiguities as to near miss vs. impact to minimize maneuver requirements. It is not practical to search with an onboard sensor because of its motion relative to all other objects, but if it knows where to look, it can significantly reduce the uncertainty in the relative orbits.



An Ekran direct broadcast television communication satellite in geosynchronous orbit exploded in 1978 while being monitored by ground telescopes. This image shows frames from a video camera that recorded the explosion, which was believed to be the result of the failure of a nickle-hydrogen battery. In February 1992, a Titan Transtage in geosynchronous orbit broke up in view of the Air Force tracking telescopes in Maui, Hawaii. There have been other unrecorded breakups in geosynchronous orbit.